INTERSPEECH 2023
20-24 August 2023, Dublin, Ireland

Vowel reduction by Greek-speaking children: The effect of stress and word length

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Abstract

This study examines vowel reduction as a function of stress and word length in 3 male and 3 female 3-, 5- and 7-year-olds, and adult controls. Participants produced triplets of two- and three-syllable words, where each Greek vowel /i, ɛ, ɐ, o, u/ was studied in the first syllable in both stressed and unstressed conditions. Measurements were made for absolute and relative duration and (non-)normalized vowel space areas. The results showed that children had longer absolute and relative vowel duration and larger non-normalized vowel space areas than adults. Vowel space areas were lower and to the left in the acoustic vowel space in relation to adults. Longer duration and larger vowel space areas were found in stressed position across all ages with an adult-like spectral reduction already present at 3 years of age but an adult-like temporal reduction from 5 years of age and onwards for unstressed vowels in both two- and three-syllable words.

Index Terms: vowel reduction, stress, word length, typical development, Greek

1. Introduction

The acoustic characteristics of vowels can vary as a function of multiple parameters including context, stress, speech rate, and word length [1-3], as well as age and gender [4-7]. Previous work has investigated vowel reduction under different conditions, such as stress, rate, and speaking style [1-3]. A difference has been established between phonological vowel reduction, i.e. change of vowels to schwa in unstressed condition in some languages, e.g. English [8], and phonetic vowel reduction leading to a reduction of the vowel space, and controlled by stress, rate, and context in languages such as Turkish [9, 10] and Polish [11]. Such phonetic vowel reduction can be characterized by formant undershoot that can occur due to temporal compression and sufficient 'locus-target' distance [1]. Reduction also depends on articulatory effort with reduced undershoot achieved by increases in the rate of formant frequency change [3].

With reference to Greek, research has shown that unstressed vowels are not neutralized to schwa [12-17]. They do, however, have reduced duration and more central position in the acoustic vowel space than stressed ones [14-17]. Vowel reduction in Greek can be influenced by several factors, such as lexical frequency [12], voicelessness of surrounding consonants [12], tempo [12, 14], prosodic position [16], speaking style [17], and lexical size [16]. With reference to lexical size, which is a parameter included in this study, Baltazani [16] observes that the unstressed vowels of pentasyllabic words are shorter and more centralized than those of trisyllabic words in adult speech, with these differences being stronger in post-stressed than in pre-stressed positions. Lexical size effects have also been reported for other languages, e.g., English and Thai; a decrease in stressed vowel duration and significant changes in formant frequencies have been reported when the number of syllables increases [3, 18-20]. The effect of lexical size, however, is much smaller on unstressed vowels [21].

While vowel reduction has been well-studied for adult speech across languages, much less is known for child speech. Even though children exhibit longer segmental duration [4, 6] and larger vowel space areas, positioned further to the left and lower in the acoustic vowel space [7, 22] than adults, the degree of vowel reduction need not necessarily differ between children and adults. For example, while Schwartz et al. [23] find that the temporal reduction between stressed and unstressed vowels is less for children up to 3 years old than adults, Kehoe et al. [24] do not find any differences in temporal reduction between children of the same age and adults. Spatial reduction has not been sufficiently studied in child populations. Research on German-speaking children aged two to six years has shown that there is variability in the reduction patterns observed [25]. Finally, to our knowledge, the effect of lexical size on vowel reduction has not been analyzed in child speech thus far. An observation of the temporal data of stressed vowels in one- and two-syllable words produced by English-speaking 2- and 4-year-olds in [26] indicates that children's degree of temporal vowel reduction due to lexical size is similar to adults'.

In view of the limited research on vowel production and reduction in child speech, the current study aims to examine: 1. developmental changes in vowel absolute duration, relative duration, and non-normalized vowel space areas; 2. stress-induced temporal and spatial vowel reduction influenced by word size in children and adults; and 3. the relationship between temporal and spatial vowel reduction in children and adults.

2. Experimental methodology

2.1. Participants

Twenty-four Greek-speaking participants took part in this study. There were 3 male and 3 female 3-, 5-, 7-year-olds, and adult controls (19;10-25;05), who came from and lived in the prefecture of Thessaloniki. According to parents' or self-reports, they presented no hearing or articulation problems.

2.2. Speech material, task, and recordings

The speech material consisted of 15 words, namely of five triplets with two disyllabic and one trisyllabic word of the form CV.CV.(CV) each. Phonotactically simple words were chosen, in order to avoid difficult segmental strings and thus missing data for young children. As shown in Table 1, in each triplet,

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one of the five Greek vowels (/i, ɛ, ɐ, o, u/) was examined in the first syllable. The environment around the target vowel was phonetically identical in each triplet and there were two stress conditions. One of the disyllabic words had the target vowel in stressed position and the other, as well as the trisyllabic word, in pre-stressed position, adjacent to the stressed syllable. Each of these words was produced five times in the carrier phrase /ˈlɛo to ____ pɐˈdu/ 'I say ____ everywhere', so a total of 1,800 vowels were studied (24 participants×15 words×5 repetitions).

Table 1: *The speech material used in the experimental task.*

Vowel Examined		Disyllabic words		Trisyllabic words
		Stressed vowel	Unstressed vowel	Unstressed vowel
First vowel	[i]	[ˈ**pi**nɐ] 'hunger'	[**pi**ˈnɐ] '(s)he is hungry'	[**pi**ˈnɐlɐ] 'glutton'
	[ɛ]	[ˈ**mɛ**li] 'honey'	[**mɛ**ˈli] 'honey-colored'	[**mɛ**ˈlisi] 'hive'
	[ɐ]	[ˈ**xɐ**li] 'mess'	[**xɐ**ˈli] 'carpet'	[**xɐ**ˈlici] 'gravel'
	[o]	[ˈ**po**li] 'city'	[**po**ˈli] 'much'	[**po**ˈliti] 'citizen'
	[u]	[ˈ**ku**nɐ] '(you) swing'	[**ku**ˈnɐ] '(s)he swings'	[**ku**ˈnɐvi] 'marten'

After a familiarization phase, the participants took part in a delayed repetition task, designed as a game on a personal computer. They heard the target word in the carrier phrase [ˈlɛo to ____ pɐˈdu] 'I say ____ everywhere' followed by the question [ˈti tus ɐpɐˈdo] 'What do I answer to them?'. They then produced the sentence with the target word. Target words were displayed one at a time on the computer screen illustrated by related pictures and, for literate participants, the orthographic representation of the target sentence.

The recordings were made in the schools of children and in the houses of adults. A Marantz PMD661 MKII recorder and an AKG C1000 S microphone placed approximately 15 cm from the participants' mouths, were used for the recordings (sampling rate at 44,100 Hz).

The research was approved by the Directorate of Primary Education of Western Thessaloniki and the Research Ethics Committee of Aristotle University on condition that recordings are not made publicly available. Signed consent forms were also obtained from the adult participants and the children's parents.

2.3. Measurements

Acoustic measurements were performed in Praat[1]. The duration of the target vowels was measured from the beginning to the end of their formant structure. In addition, the duration of the first two syllables of each test word was measured. Relative duration was calculated in relation to this disyllabic part of the word, i.e. (vowel duration/ duration of the disyllabic part) ×100.

F1 and F2 formants were measured from the temporal midpoint of each target vowel. On the basis of Adank et al. [27], who found that the Lobanov method can control for anatomical differences and preserve phonemic variation more effectively than the other normalization methods, F1 and F2 values were normalized with the normLobanov function in R[2] and then rescaled based on the minimum and maximum values of normalized F1 and F2. Vowel space areas were then calculated for both normalized and non-normalized values, according to [14]. We extracted three vowel space areas from each participant [one for stressed vowels (stressed), one for unstressed vowels in two-syllable words (unstressed-2), and one for unstressed vowels in three-syllable words (unstressed-3)]. In total, 72 vowel space areas for both normalized and non-normalized values were calculated.

Statistical analyses were performed in R using linear mixed model ANOVAs, Tukey's HSD post-hoc tests, Wilcoxon tests, and Pearson correlations. The mixed models were obtained with the nlme::lme function, with Speaker as a random effects variable. For absolute and relative duration, the fixed effects variables were Age, Gender, Stress/Length (stressed, unstressed-2, and unstressed-3), and Vowel. For vowel areas, the fixed effects variables were Age, Gender, and Stress/Length. Due to the existence of heterogeneity in some independent variables, the varIdent function was used in the mixed models.

3. Results

3.1. Absolute duration

The main effect of age ($F(3, 16) = 25.2348$, $p < .0001$) showed that absolute vowel duration decreased with age. Specifically, 3-year-olds differed significantly from 7-year-olds and children of all ages from adults; no other significant differences were found (e.g. means: 3-year-olds: 138 ms, 5-year-olds: 129 ms, 7-year-olds: 112 ms > adults: 74 ms). The main effect of stress/length ($F(2, 1664) = 711.4703$, $p < .0001$) indicated significant differences in absolute duration between conditions, i.e. stressed (141 ms) > unstressed-2 (104 ms) > unstressed-3 (96 ms). The Age×Stress/Length interaction ($F(6, 1664) = 17.2818$, $p < .0001$) showed that the stressed vowel differed significantly from the unstressed vowel in both conditions (unstressed-2 and unstressed-3) across ages while no significant differences were found between the vowels in the two unstressed conditions except for the 5-year-olds.

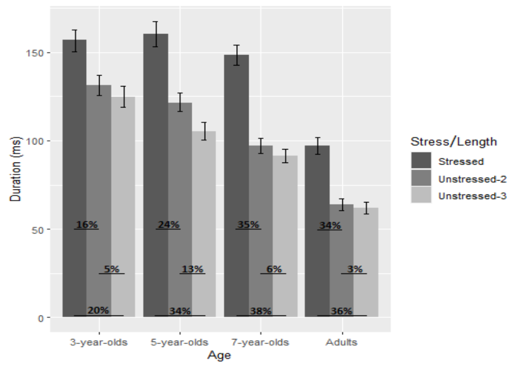

Figure 1: *Absolute vowel duration (in ms) and percentage of reduction by age and stress/length condition.*

Figure 1 presents absolute vowel duration and the percentage of reduction between all conditions (i.e. stressed and

[1] P. Boersma, and D. Weenink, Praat: doing phonetics by computer [Computer program]. Version 6.3.08, 1992-2023, retrieved 10 February 2023 from https://www.praat.org.

[2] R Core Team, R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, 2022. https://www.R-project.org/.

unstressed-2, unstressed-2 and unstressed-3, and stressed and unstressed-3). Wilcoxon tests were carried out to compare the percentages of reduction of each child age group with adults. Three-year-olds had the lowest percentage of reduction between the stressed and unstressed conditions (16% and 20%) which was significantly different from that of adults (34 % and 36%; p = 0.03 and p = 0.045, respectively). For the other groups, the percentage of reduction was similar between the stressed and unstressed-3 conditions (34% for 5-year-olds, 38% for 7-year-olds, and 36% for adults). The percentage of reduction between the stressed and unstressed-2 conditions showed a more gradual developmental path with the smallest degree of reduction for the 3-year-olds (16%), as mentioned above, greater reduction for the 5-year-olds (24%) and the largest for the 7-year-olds and adults (35% and 34%, respectively). Despite five-year-olds' smaller percentage of reduction between the stressed and unstressed-2 conditions compared to adults, they did not differ from the adult group, suggesting that an adult-like reduction in absolute duration between the stressed and unstressed conditions was present at age 5. It is interesting, however, that between the two unstressed conditions, only five-year-olds' reduction (13%) differed significantly from that of adults (3%; p = 0.03).

The main effect of gender showed no differences. Finally, the main effect of vowel (F(4, 1664) = 433.9948, p < .0001) showed that vowels differed in absolute duration in the order [o] (132 ms), [ɐ] (127 ms), [ɛ] (125 ms) > [i] (96 ms) > [u] (87 ms) ([o] and [ɛ] were also significantly different).

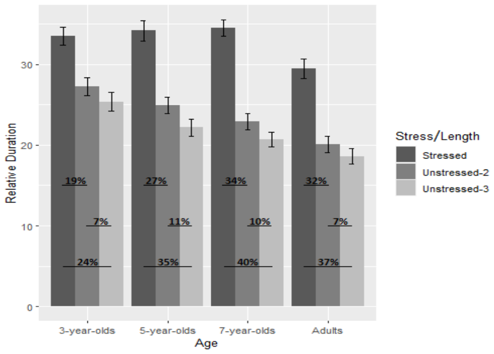

Figure 2: *Relative vowel duration and percentage of reduction by age and stress/length condition.*

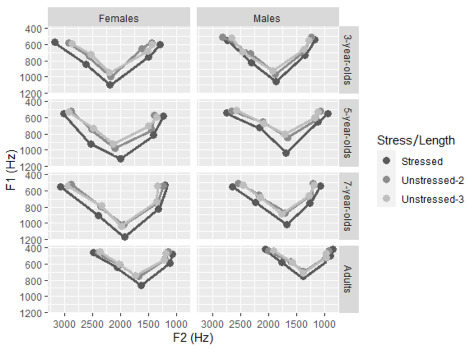

Figure 3: *Non-normalized F1×F2 vowel spaces (in Hz) by age, gender, and stress/length condition*

3.2. Relative duration

This section reports the analysis on relative duration which was measured to control for differences in speech rate among individuals. The main effect of age (F(3, 16) = 9.969, p < .0001) showed that there was a tendency for relative duration to decrease with age. Although differences among child groups were not significant, children of each age had significantly longer duration than adults (means: 3-year-olds: 29, 5-year-olds: 27, 7-year-olds: 26 > adults: 23). The Stress/Length main effect (F(2, 1664) = 1404.131, p < .0001) showed significant differences in relative duration between conditions, i.e. stressed (33) > unstressed-2 (24) > unstressed-3 (22). This reduction pattern was present across all ages (Age×Stress/Length interaction: F(6, 1664) = 16.034, p < .0001).

As seen in Figure 2, the degree of reduction between the stressed and unstressed conditions was quite small in the 3-year-olds (19% and 24%) and differed significantly from that of adults (32% and 37%; p = 0.03 for both comparisons). The children of the remaining age groups had quite similar behavior to adults, so an adult-like reduction in relative duration was mastered by the age of 5 for all conditions. The smallest percentage of reduction was found between the unstressed-2 and unstressed-3 conditions, not exceeding 11% but significant for each age group.

No effect of gender was found. Finally, the vowel main effect (F(4, 1664) = 735.044, p < .0001) showed that there were differences in relative duration among vowels in the order of [ɛ] (30.4), [o] (30.3), [ɐ] (29.9) > [i] (21.2) > [u] (18.8) indicating significantly shorter duration for the close in relation to the mid and open vowels, similarly to the absolute duration results.

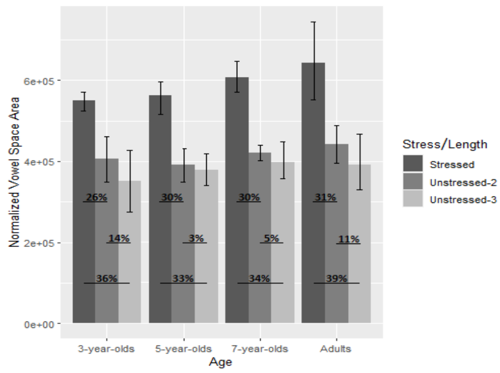

Figure 4: *Normalized vowel space areas and percentage of reduction by age and stress/length condition.*

3.3. Vowel space areas

Regarding non-normalized vowel space areas, the main effect of age (F(3, 16) = 8.9867, p = 0.001) indicated that children of all ages had significantly larger vowel areas, located lower and further to the left in the acoustic vowel space compared to adults (Figure 3: means: 3-year-olds: 394,422 Hz^2, 5-year-olds: 410,702 Hz^2, 7-year-olds: 439,829 Hz^2 > adults: 218,023 Hz^2). The Stress/Length main effect (F(2, 32) = 59.2394, p < .0001) revealed that vowel areas decreased in the order: stressed (466,440 Hz^2) > unstressed-2 (321,613 Hz^2), unstressed-3 (309,178 Hz^2). No significant differences were found between the two unstressed conditions across all ages. The vowel areas were therefore similar in these conditions and, as shown in Figure 3, the unstressed vowel spaces were located within the stressed ones. The gender main effect (F(1, 16) = 7.0391, p = 0.0174) showed that females had significantly larger vowel areas than males (females: 410,019 Hz^2 > males: 321,379 Hz^2).

To control for variation due to anatomical differences, we also calculated the vowel areas from the normalized values of F1 and F2. For these areas, only the Stress/Length main effect was significant ($F(2, 32) = 77.481$, $p < .0001$); vowel areas decreased in the order: stressed (595,359) > unstressed-2 (408,615), unstressed-3 (381,913) (no significant differences were present between the unstressed conditions). In fact, the percentages of reduction were similar to those obtained for the non-normalized areas. Figure 4 presents the normalized vowel areas and the percentage of reduction by stress/length condition for each age group. Wilcoxon tests showed that the degree of spatial reduction did not differ significantly between children and adults in any condition.

3.4. Correlation between relative duration and normalized vowel space areas

On the basis of the predictions of the duration-dependent undershoot model [1, 3], the relationship between temporal and spatial reduction was examined. A correlation analysis between relative duration and normalized vowel space areas was carried out. Normalized measures were used to control for variations in speech rate and anatomical differences. Figure 5 shows that for all ages there was a positive correlation between relative duration and normalized vowel space areas, i.e., the longer the vowel duration, the larger the vowel space area. The correlation was strong for 5-, 7-year-olds, and adults ($r \geqslant 0.85$). For the youngest children, a moderate correlation was observed ($r = 0.68$), which, however, was also significant ($p = 0.0019$).

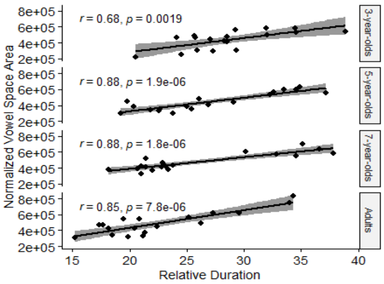

Figure 5: *Pearson correlation between relative duration and normalized vowel space areas by age*

4. Discussion

This study focused on the effect of stress and lexical size on vowel reduction by Greek-speaking children. Temporal reduction in absolute and relative duration measures and spatial reduction in non-normalized and normalized vowel space areas were investigated in 3-, 5- and 7-year-old children of both genders and compared to adult controls.

Vowel production varied as a function of age. Children of all ages had longer absolute and relative vowel duration than adults. They also had larger non-normalized vowel space areas, located lower and further to the left in the acoustic vowel space compared to adults', results compatible with [7, 22]. These temporal and spectral differences between children and adults may result from differences in speech motor control [4, 6] and from anatomical differences [7].

Stress and lexical size also had a significant effect on absolute and relative duration, and (non-)normalized vowel space areas across all ages. Stressed vowels in disyllabic words were significantly longer than their unstressed counterparts in disyllabic and trisyllabic words for both absolute and relative duration. Although there was a tendency for longer absolute and relative duration for the unstressed vowel in the disyllabic than the trisyllabic words, only differences in relative duration between the two unstressed conditions were systematically significant. Similar effects were present in the spectral characteristics. Significantly larger (non-)normalized vowel space areas for the stressed than the unstressed vowels were found. While there was a tendency for larger vowel space areas for the unstressed vowel of the disyllabic than the trisyllabic words, no significant differences were found. The absence of large differences between the unstressed conditions may be due to the fact that the effect of word length was studied for the pre-stressed vowel. Baltazani [16] has shown that vowel reduction due to lexical size is smaller in pre-stressed than in post-stressed position in Greek.

The study has also examined the degree of temporal and spectral vowel reduction across ages. Although duration was significantly longer for children of all age groups than adults, an adult-like degree of temporal vowel reduction was acquired for the two older age groups (5- and 7-year-olds). In particular, for both absolute and relative duration, stress-related reduction effects were small for the 3-year-olds while the two older 5- and 7-year-old age groups had similar temporal reduction patterns to adults. An observation of the percentages of temporal reduction across age groups (Figures 1 and 2) reveals an interesting developmental path with gradually larger reduction for both unstressed conditions across age groups. In fact, a tendency for somewhat larger reduction appeared for the 7-year-old children than adults, which was not significant. The degree of reduction in absolute duration for disyllabic words (34%) was lower to that reported in [14, 28] for Greek-speaking adults (approaching or exceeding 40%); this may be due to differences in the method between studies.

Concerning spectral vowel reduction, across all age groups, there was a smaller vowel space for the unstressed vowels which was placed within the vowel space of the stressed ones, displaying some degree of centralization for the vowels in most cases, but not reduction to a schwa. The degree of spatial reduction approached or exceeded 30%, a percentage similar to that of studies on Greek-speaking adults [14, 28]. Our data has also shown that children of all age groups reduced their vowel space areas in the unstressed conditions to a similar degree to adults, for both non-normalized and normalized data. Thus, a somewhat different developmental path in spectral reduction compared to temporal reduction suggests some degree of independence between spatial and temporal reduction.

Interestingly, positive correlations between relative duration and normalized vowel space areas at all ages revealed that a decrease in duration also led to a decrease in vowel areas suggesting that temporally reduced vowels could not reach their ideal acoustic targets in line with the duration-dependent undershoot model [1, 3]. These correlations were very strong for participants from 5 years and above ($r \geqslant 0.85$) and more moderate for 3-year-olds ($r = 0.68$). These findings may suggest greater variation in spatio-temporal organization among younger 3-year-old children compared to older 5- and 7-year-old ones. Temporal reduction due to stress and word length was found to be smaller for this group while spectral reduction was similar to the other groups. Overall, our data suggest an ongoing developmental path toward the adult pattern of vowel production and vowel reduction. For a better insight, however, it would be useful to study more participants, age groups, and prosodic positions.

5. Acknowledgments

Thanks to the participants and Tasos Paschalis for the technical support.

6. References

[1] B. Lindblom, "Spectrographic study of vowel reduction," *The Journal of Acoustical Society of America*, vol. 35, pp. 1773-1781. 1963.

[2] M. Fourakis, "Tempo, stress, and vowel reduction in American English," *The Journal of Acoustical Society of America*, vol. 90, no. 4, pp. 1816-1827, 1991.

[3] S. J. Moon, and B. Lindblom, "Interaction between duration, context, and speaking style in English stressed vowels," *The Journal of Acoustical Society of America*, vol. 96, no. 1, pp. 40-55, 1994.

[4] M. Gerosa, S. Lee, D. Giuliani, and S. Narayanan, "Analyzing children's speech: An acoustic study of consonants and consonant-vowel transition," in *Acoustics, Speech, and Signal Processing Proceedings*, Toulouse, 1988, pp. 393-396.

[5] P. A. Busby, and G. L. Plant, "Formant frequency values of vowels produced by preadolescent boys and girls," *The Journal of the Acoustical Society of America*, vol. 97, pp. 2603-2606, 1995.

[6] S. Lee, A. Potamianos, and S. Narayanan, "Acoustics of children's speech: Developmental changes of temporal and spectral parameters," *The Journal of Acoustical Society of America,* vol. 105, pp. 1455-1468, 1999.

[7] H. K. Vorperian, and R. D. Kent, "Vowel acoustic space development in children: A synthesis of acoustic and anatomic data," *Journal of Speech, Language, and Hearing Research*, vol. 50, no. 6, pp. 1510-1545, 2007.

[8] W. R. Tiffany, "Non-random sources of variation in vowel quality," *The Journal of Speech and Hearing Research*, vol. 2, pp. 305-317, 1959.

[9] A. K. Konrot, "Physical correlates of linguistic stress in Turkish," *University of Essex Language Centre Occasional Papers*, vol. 40, pp. 26-53, 1981.

[10] M. Sabev, and E. Payne, "A cross-varietal continuum of unstressed vowel reduction: Evidence from Bulgarian and Turkish," in *Proceedings of the 19th International Congress of Phonetic Sciences*, Melbourne, 2019, pp. 1164-1168.

[11] P. Strycharczuk, and P. Jurgec, "Prosodic influences on formant frequencies of Polish vowels," in *3rd Newcastle Postgraduate Conference in Theoretical and Applied Linguistics*, Tromsø, 2008, pp. 1-7.

[12] R. M. Dauer, "The reduction of unstressed high vowels in modern Greek. *Journal of the International Phonetic Association*, vol. 10, pp. 17-27, 1980.

[13] K. Nicolaidis, "Vowel reduction: Evidence from Greek," *Speech Research Laboratory, University of Reading, Work in Progress*, vol. 6, pp. 77-121, 1990.

[14] M. Fourakis, A. Botinis, and M. Katsaiti, "Acoustic characteristics of Greek vowels," *Phonetica*, vol. 56, pp. 28-43, 1999.

[15] K. Nicolaidis, "Acoustic variability of vowels in Greek spontaneous speech," in *Proceedings of XVth International Congress of Phonetic Sciences*, Barcelona, 2003, pp. 3221-3224.

[16] M. Baltazani, "Prosodic rhythm and the status of vowel reduction in Greek," in *Selected Papers on Theoretical and Applied Linguistics from the 17th International Symposium on Theoretical & Applied Linguistics*, Thessaloniki, 2007, pp 31-43.

[17] A. Lengeris, "Phonetic vowel reduction in Standard Modern Greek," in *Selected Papers of the 10th ICGL*, Komotini, 2012, pp. 401-407.

[18] I. Lehiste, "Some factors affecting the duration of syllable nuclei in English," *Salzburger Beiträge zur Linguistik*, vol. 1, pp. 81-104, 1975.

[19] K. L. Haley, and H. B. Overton, "Word length and vowel duration in apraxia of speech: The use of relative measures," *Brain and Language*, vol. 79, pp. 397-406, 2001.

[20] J. Gandour, S. Dechongkit, S. Ponglorpisit, and P. Boongird, "Intraword timing relations in Thai after unilateral brain damage," *Brain and Language*, vol. 45, pp. 160-179, 1993.

[21] E. Farnetani, and S. Kori, "Effects of syllable and word structure on segmental durations in spoken Italian," *Speech Communication*, vol. 5, pp 17-34, 1986.

[22] A. Sfakianaki, "Acoustic characteristics of Greek vowels produced by adults and children," in *Selected Papers on Theoretical and Applied Linguistics from the 14th International Symposium*, Thessaloniki, 2002, pp. 383-394.

[23] R. G. Schwartz, K. Petinou, L. Goffman, G. Lazowski, and C. Cartusciello, "Young children's production of syllable stress: An acoustic analysis," *The Journal of the Acoustical Society of America*, vol. 99, no. 5, pp. 3192-3200, 1996.

[24] M. Kehoe, C. Stoel-Gammon, and E. H. Buder, "Acoustic correlates of stress in young children's speech," *Journal of Speech and Hearing Research*, vol. 38, pp. 338-350, 1995.

[25] K. Schneider, and B. Möbius, "Production of word stress in German: Children and adults," in *Proceedings of Speech Prosody (3rd International Conference)*, Dresden, 2006, pp. 333-336.

[26] B. L. Smith, "Temporal aspects of English speech production: A developmental perspective," *Journal of Phonetics*, vol. 6, pp. 37-67, 1978.

[27] P. Adank, R. Smits, and R. van Hout, "A comparison of vowel normalization procedures for language variation research," *The Journal of the Acoustical Society of America*, vol. 116, no. 5, pp. 3099-3107, 2004.

[28] K. Nicolaidis, and A. Sfakianaki, "Acoustic characteristics of vowels produced by Greek intelligible speakers with profound hearing impairment II: The influence of stress and context," *International Journal of Speech-Language Pathology*, vol. 18, no. 4, pp. 388-401, 2016.